Fruit and Vegetable Waste: A Taste of Future Foods

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Abstract

Fruits and vegetables are the unexploited horticulture products that hold the largest share in the food waste produced globally. Regardless of being consumed in different forms such as raw, minimally processed and well-processed food and an abundant source of promising invaluable bioactive compounds, a considerable proportion in the form of peels, seeds, skins, rinds and pomace is wasted. This waste can be utilized for the extraction of functional compounds such as dietary fibre, carotenoids, polyphenols, essential oils, vitamins, minerals and certain enzymes. Based on the chemical nature of the compounds and the residue, diverse range of processing strategies, like enzyme-assisted extraction, supercritical fluid extraction, pulse electric field, microwave-assisted extraction and ultrasound-assisted extraction, have been employed for their extraction and purification. Such bioactive compounds exert a productive influence to improve human health, owing to their antioxidant, anticancer, anti-inflammatory and anti-allergic properties. With the technological advancement, these compounds pave the way for the production of enriched or fortified foods and food additives, the segment, which is expanding tremendously due to excellent consumer demand for naturally occurring, healthy and safe products. The chapter aims at providing a comprehensive knowledge on the upgradation of large volumes of fruit and vegetable waste to provide potential bioactive compounds and adopting a zero waste approach.

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6.1 Introduction

With the advent of increasing population size, changeable diet patterns and surging consumer demand for convenient and wholesome foods, the food-processing industry is expanding exponentially to deliver more and more variants in pre-processed and packaged foods. The demand for fruits and vegetables has amplified substantially, by the presence of natural biologically active compounds, which provides physiological benefits to human health. The technological advancement has brought an upsurge in the production of these seasonal products, yet, improper handling, poor infrastructure facilities and inadequate utilization strike way for extensive losses of these important commodities. The process of converting raw fruits and vegetables into value-added processed products requires the removal of unwanted portions such as stems, stalks, peels, rinds, stones, seeds etc. which additionally account for the production of significant wastes in the form of by-products and residues (Sagar et al. 2018). The waste so produced is highly complex due to the availability of a broad range of fruits and vegetables which undergo a series of processing operations from production to retail stage (Kodagoda and Marapana 2017). These losses and wastes indirectly squander critical reserves (water, land, energy, chemicals, fertilizers and labour), provoking a matter of global concern in terms of its disposal, economy, environmental impact and potential health implications (Vilariño et al. 2017).

According to the Food and Agriculture Organization of the United Nations, out of the total production of fruits and vegetables worldwide, 45% is wasted every year, which is the largest amongst all the food sectors. Regardless of this, India secured second position globally in the production of fruits and vegetables, beholds approximately 4.58–15.88% wastage of such products annually by cause of insufficiency of modern harvesting practices and cold storage rooms. Kummu et al. (2012) reported the quantitative segmentation of waste generated during various operations such as at the time of production (24–30%), post-harvest stage (20%) and consumption (30–35%). The quantity and quality of waste produced vary considerably from commodity to commodity, some of them may produce as high as 25–30% of waste containing potentially active biomolecules. The production of minimally processed fruits and vegetables requires operations such as peeling, slicing, cutting, dicing etc. which generate significant amounts of wastes, as exemplified in the case of mandarins, where peels account for 16% of the whole product. Dicing of papaya generates waste in the form of peel (8.5%), seeds (6.5%) and unusable pulp (32%) (Joshi et al. 2012). Many of the fruits and vegetables are converted into convenient processed products such as juices spawning roughly 5.5 million metric tonnes (MMT) of waste. Wine-producing industries utilize grapes as the key ingredient and produce around 5–9 MMT annually (Schieber et al. 2001). Furthermore, the shelf-life of horticulture produce is limited and can be extended to months and years by using preservation techniques like canning and freezing, which together generate about 6 MMT of solid waste annually, comprising leaves, stalks and stems.

As this enormous amount of waste generated poses a serious threat to the environment and country's economy, there is need to devise sustainable alternatives to further exploit such commodities. These wastes can act as a valuable source of phytochemicals, particularly phenolic compounds, phenolic acids, enzymes, organic acids, proteins and flavouring and colouring agents, which can be utilized as dietary supplements, nutraceutical compounds or functional foods and as source of food additives. The conversion of these wastes produced into a valuable product favours the horticulture-based industries to reduce their cost of treatment, generate additional profits and boost their competitiveness (Gowe 2015).

6.2 Potential Bioactive Components in Fruit and Vegetables Waste

The promising biologically active compounds extracted from fruits and vegetables waste are composed of an exceptional pool of molecules, comprising dietary fibre, phenolic compounds, antioxidants, pigments, enzymes and antimicrobial compounds, which are subsidized in the trimmings, seeds, peels, stems, shells, pomace after juice extraction and oil cakes. Table 6.1 demonstrates the wide range of bioactive factors from fruits and vegetables waste. Such waste is a vital source of various nutrients likewise carbohydrates, proteins, fats, minerals, fibres, etc. The various benign bioactive compounds present in waste are:

6.2.1 Phenolic Compounds

The waste obtained in the course of minimal processing of the fruits is enriched in total phenolics and flavonoids when compared to the final products, as more evident in mango seeds and peels than pulp. Phenolics are considered as the collateral metabolites of fruits and vegetables obligated for their sensory and nutritional profile. Phenolic compounds, constituting one or more aromatic rings and incorporating one or more hydroxyl groups in basic structure, are known to possess some sort of antioxidant activity by virtue of free radical inhibition activity (Balasundram et al. 2006). They serve fundamental duties in the reproduction and development of the plants, participate in defence mechanisms against parasites, pathogens and ultraviolet (UV) irradiation, and further provide colour to plants. Moreover, dietary phenolic compounds may bring additional health benefits related to the diminished risk of generating chronic diseases (Song et al. 2010).

Previous studies have also illustrated that peel and seeds parts are having an abundance of phytochemical compounds in relation to edible tissue. Czech et al. (2020) observed that lemon, orange, and grapefruit peels contain 15% greater total

Table 6.1 Bioactive compounds in fruits and vegetables waste

Fruit/ vegetable	Type of waste	Bioactive components	References
Apple	Pomace	Hydroxycinnamates, phloretin glycosides, quercetin, glycosides, catechins, procyanidins	Teleszko and Wojdyło (2015)
Banana	Bract	Cyanidin, anthocyanidins (delphinidin, pelargonidin, peonidin, petunidin, malvidin)	Alexandra Pazmiño-Durán et al. (2001)
Banana	Peel	Carotenoids (palmitate or caprate, xanthophylls, laurate)	Subagio et al. (1996)
Citrus fruits	Peel and solid residues	Eriocitrin, hesperidin, naringenin	Coll et al. (1998)
Cranberry	Leaves	Catechin, procyanidin B1, (−) epicatechin, myricetin-3-xylopyranoside, quercetin-3-O-galactoside, dimethoxymyricetin-hexoside, methoxyquercetin-pentoside	Teleszko and Wojdyło (2015)
Grapes	Seed	Procyanidins	Saito et al. (1998)
Grapes	Pomace	Catechins, anthocyanins, stilbenes, flavonol glycosides	Schieber et al. (2001)
Grapes	Skin	Catechin, epicatechin, epigallocatechin, epicatechin gallate	Souquet et al. (1996)
Mango	Seed Kernel	Gallates, gallotannins, gallic acid, ellagic acid	Schieber et al. (2000)
Mango	Peel	Flavonol glycosides	Schieber et al. (2000)
Olive	Peel and oil waste water	Myricetin, ferulic, sinapic, caffeic, gallic, and ellagic acids, oleuropein and hydroxytyrosol derivatives	Moo-Huchin et al. (2015)
Carrot	Pomace	Carotene (α and β)	Schieber et al. (2001)
Garlic	Husk	Di-ferulic acid, hydroxybenzoic acid, p-coumaric acid, caffeic acid-O-glucoside, coumaric acid-O-glucoside, N-caffeoylputrescine	Kallel et al. (2014)
Onion	Skin	Quercetin 3,40-O-diglucoside and quercetin 40-O-monoglucoside	Price and Rhodes (1997)
Potato	Peel	Chlorogenic, gallic, protocatechuic and caffeic acids, chlorogenic acid isomer II	Choi et al. (2016)
Red beet	Peel	L-tryptophan, *p*-coumaric and ferulic acids, cyclodopa glucoside derivatives	Kujala et al. (2001)
Tomato	Peel	Lycopene	Sharma and Le Maguer (1996)

phenolic compounds when compared with pulp of the same fruits. Likewise, peels of peaches, apples and pears along with yellow and white flesh nectarines yield double the quantity of total phenolic compounds as found in their fruit pulp. The phenolic compounds of bananas in the edible pulp part comprise of 232 mg/100 g of dry weight, which accounts approximately to 25% of the peel portion (Someya et al. 2002). Similarly, 249.4 mg/g of phenolic compounds is present in pomegranate peels, whilst 24.4 mg/g in the pomegranate pulp (Wolfe and Liu 2003). Interestingly, total phenolic compounds of seeds of various fruits as mangoes, longans, jackfruit and avocados were noticeably exceeding the edible portion (Soong and Barlow 2004). The seeds and peels of tomatoes are enriched with phenolic compounds than tomato pulp. Distinctly, 12 genotypes of tomato were under investigation for phenolic compound assessment, which resulted in curtailing levels in the flesh, 9.2–27.0 mg/100 g, with respect to 10.4–40.0 mg/100 g in the peel portion (Del Valle et al. 2006). Besides phenolic compounds, the peel also contains reasonable amounts of ascorbic acid, flavonoids and lycopene pigment when compared with pulp and seeds in several tomato cultivars (Toor and Savage 2005). Surprisingly, phenolic content of the waste of fruits and vegetables processing is leading tenfold than pulp. Such by-products could be treasured as the origin of phytochemicals for human health.

Zeyada et al. (2008) categorized the fruits and vegetables waste as per the richness in phenolic content in the following booming order: potato peel > watermelon peel > cucumber peel > tomato peel > olive leaves. Date seeds are also an exemplary source of antioxidants and phenolic compounds (Al-Farsi and Lee 2008). Date seed oil possesses a higher amount of phenolic compounds than nearly all edible oils, except the olives (Besbes et al. 2005). The seed waste extracts of cucumber, squash, bitter melon, bottle gourd and Indian round gourd have been observed to be extremely effective against certain microbes, such as *Escherichia coli*, *Fusarium oxysporium*, *Serratia marcescens*, *Streptococcus thermophilus* and *Trichoderma reesei* (Sonia et al. 2016), perhaps because of their high phenolic content. A huge waste produced by the citrus industry accounts for its peel and seed residues that is approximately 50% of the total fruit (Ignat et al. 2011). This waste encompasses phenolic compounds in supreme quantity when compared with the edible portion (Balasundram et al. 2006). Enriched concentrations of phenolics have also been found in peels of other fruits (apples, peaches and pears) in comparison to their edible parts (Gorinstein et al. 2001). It was reported that phenolic compounds found in banana pulp are merely the 25% of that contained in the peel (Someya et al. 2002). In conjunction with phenolic compounds, lofty portion of catecholamines, dopamine and levodopa were also present in banana peels (Gonzalez-Centeno et al. 2010). The peels of varied varieties of clingstone peaches were illustrated to obtain a larger concentration of phenolic compounds (more than 2.0–2.5 times) than the flesh (Chang et al. 2000).

6.2.2 Flavonoids

Polyphenolic compounds are classified into flavonoids, tannins, phenolic acids, stilbenes and lignans. Amongst diverse types of fruits, vegetables and other plant-based foods, flavonoids constitute one of the biggest bunches of phenolic compounds. More than 4000 flavonoids have been described up to now in the literature. The common generic structure of flavonoids is constituted of two aromatic rings (A and B rings) associated by three carbons that are generally present in an oxygenated heterocyclic ring. Distinction amongst generic structures of the heterocyclic ring categorizes them as flavonols, flavones, flavanols (catechins), flavanones, anthocyanidins and isoflavonoids. Flavonols (galangin, kaempferol, myricetin and quercetin), flavones (apigenin, luteolin and chrysin), flavanols (catechin, epicatechin, epigallocatechin (EGC) and epicatechin gallate (ECG)), flavanones (eriodictyol, naringenin and hesperidin), anthocyanidins (cyanidin, delphinidin, malvidin, peonidin, petunidin and pelargonidin) and isoflavonoids (genistein, daidzein, glycitein and formononetin) are commonly known flavonoids, which are present in our diet (Liu 2013). Naturally, flavonoids are present in the form of conjugates in glycosylated or esterified forms in normal situation, though they can also arise as aglycones, particularly due to the effects of food processing. Flavonoids have been recognized as bound to more than 80 different sugars (Hollman and Arts 2000). Anthocyanins are responsible for the red and blue colours of several fruits, vegetables and whole grains. Whereas, most of the occurrence of flavonoids is observed in oranges and orange juices and considered as the vital sources of flavonoid compounds such as hesperedin and naringenin. The dominant portions of flavonoids in apples are cyanides, quercetin and epicatechin. The most plentiful flavonoids in raisins are quercetin glycoside, quercetin, catechin, epicatechin, kaempferol glycoside, kaempferol and rutin (Parker et al. 2007; Zhao and Hall 3rd 2008). Apple pomace as fruit waste possesses an exceeding amount of flavonoids (2153–3734 mg/kg) in the form of isorhamnetin, kaempferol, quercetin, rhamnetin, glycoconjugates, procyanidin and epicatechin. Peel and pulp portion of citrus fruits contain flavones and flavanones in a very high amount, constituting major compounds such as apigenin-glucoside, diosmetin-glucoside, eriocitrin and hesperidin and narirutin. The flavonoid contents of mango kernel seed are profoundly better than pulp, as the former contains 7200–13,000 mg/kg of quercetin, isoquercetin and fisetin. Similarly, banana peel secures the vital content of flavonols (1019.6 mg/kg) in terms of rutin, quercetin, kaempferol, myricetin and laricitrin. Other than these, various berries' (bilberries, blueberries, cranberries and lingonberries) waste as press residue contains an immense quantity of anthocyanins (Ben-Othman et al. 2020). Grape juice and white wine industries produce by-products that include seeds and skins, and are vital sources of plentiful flavonoids, specifically monosaccharides, oligosaccharides and polymeric proanthocyanidins (Shrikhande 2000). In vegetables waste, beetroot pomace, stalks, stems and florets of broccoli and cauliflower withhold a fair quantity of flavonoids. Flavonoid composition of beetroot pomace is composed of catechin, epicatechin and rutin. Whilst flavonoid constituents of broccoli and cauliflower waste are kaempferol and quercetin (Thomas et al. 2018). Agarwal et al. (2012) considered the cucumber peel as an economical source of flavonoids for industrial purposes.

6.2.3 Phenolic Acids

Phenolic acids, which are one of the prime sources of dietary phenolics, can be subdivided into two main groups, as hydroxybenzoic acid and hydroxycinnamic acid derivatives (Liu 2013). Derivatives of hydroxybenzoic acid include p-hydroxybenzoic, gallic, vanillic, protocatechuic and syringic acids. The presence of phenolic acids is usually noticed in food in the bound form and particularly, these are constituents of cell wall structural components such as lignins and hydrolysable tannins, cellulose and proteins through ester bonds. These are commonly attached to fibre, protein, sugar, sugar derivatives and organic acids in different plant foods. The p-coumaric, ferulic, caffeic and sinapic acids are counted under the hydroxycinnamic acid derivatives (Liu 2004). In general, the primary abundance of ferulic acids is found in the seeds and leaves parts of plants, majorly conjugated via covalent bonds with mono- and disaccharides, glycoproteins, plant cell wall polysaccharides, polyamines, insoluble carbohydrate biopolymers, lignin and fibres (Liu 2004). Application of food processing with respect to thermal processing, pasteurization, freezing and fermentation assists in the release of the free and soluble forms of conjugated ferulic acids from the bound form of phenolic acids (Dewanto et al. 2002). In almost all the plants, caffeic, ferulic, p-coumaric, protocatechuic and vanillic acids are present in more or less quantity. Chlorogenic acids and curcumin are primary derivatives of hydroxycinnamic acids existing in plants. Chlorogenic acids, being the esters of caffeic acids, behave as substrates during enzymatic oxidation for inducing browning, especially in apples and potatoes. The most abundant phenolic acids of raisins are caftaric acid, coumaric acid, chlorogenic acid and gallic acid (Zhao and Hall 3rd 2008). The seed, rind and peel of fruits and vegetables acquire an exceeding quantity of phenolic compounds. Further, potato peel was exhibited to behold the 50% of phenolic compounds out of the total bioactive components' quantity (Friedman 1997). Choi et al. (2016) examined the "Superior" variety of the Korean potato and described the larger amount of phenols with respect to chlorogenic acid, chlorogenic acid isomer II and caffeic acid. All remaining fruits and vegetables waste is usually composed of a tough cell wall structure as stalks, stems, peel, seeds, kernel etc., where phenolic acids exist in various forms and quantities.

6.2.4 Organic Acids

A number of organic acids viz. citric acid, succinic acid, malic acid, acetic acid and tartaric acid are general elements of fruits and their successive by-products. These acids have been utilized conventionally as preservatives in the food industry, owing to their antimicrobial efficacy by changing the pH levels of food products. Commonly, bacteria best grow at pH around 6.5–7.5, yet tolerant to the pH range of 4–9, whereas yeasts and molds can grow conveniently at low pH values. Thus, the increment in acidity (by formulating organic acids) of individual food is effective for limiting microbial growth (Raybaudi-Massilia et al. 2009). Microorganisms' lysis occurs by H^+ attack on cell walls, membranes, protein synthesis systems, metabolic enzymes and DNA (Tripathi and Dubey 2004). Organic acids like citric and lactic acids have found applications in food, cosmetic and chemical industries. The production of citric acid can be accomplished efficiently by the fermentation of fruits and vegetables waste using distinct molds, yeasts and bacteria (Swain et al. 2011). Coffee husk and cassava bagasse are extraordinary substrates for *Aspergillus niger* to recover citric acid in good quantity (Vandenberghe et al. 2000). By-product of apple juice or wine industry, apple pomace has been a popular substrate material for *Aspergillus niger* to achieve up to 80% of citric acid as well (Dhillon et al. 2011). Pineapple, mandarins and mixed fruits waste yielded 51.4%, 50% and 46.5% of citric acid, respectively, with the same mold substrate (Prabha and Rangaiah 2014). Imandi et al. (2008) extracted utmost quantity of citric acid by processing pineapple waste via employment of *Yarrowia lipolytica* yeast. Lactic acid holds the prime importance in the carboxylic acid group by virtue of its distinguished usefulness in both kind of industries of food as well as of the non-food. Lactic acid works as an acidulant and preservative in food industry. The production of lactic acid is intricate with regard to the cost of raw material. John et al. (2006) determined that the *Lactobacillus delbrueckii* bacteria can convert total sugars of cassava bagasse into 99% of lactic acid under optimized conditions. Hence, the by-products of fruits and vegetables can easily be utilized for producing lactic acid by employing various microorganisms. Bacteria as *Lactobacillus delbrueckii*, *Lactobacillus casei* and *Lactobacillus plantarum* have been prominently employed to yield lactic acid from potato peel, mango, orange, green peas, sweet corn and cassava residue as substrates (Panda et al. 2016).

6.3 Isolation of Bioactive Elements From Fruits and Vegetables Waste

A classic approach to reduce the burden of high amounts of fruits and vegetables waste and to transform it into valuable products requires extraction of the bioactive compounds. Diverse ranges of techniques are available which can be utilized for isolation and purification of these compounds which can later be exploited as flavouring agents, colouring agents, additives, nutraceutical compounds, functional polymers, etc. The extraction method employed is analogous to the type of compound to be extracted and the quantities of such compounds in the waste material. These methods can be categorized into conventional/traditional and novel techniques.

6.3.1 Conventional Extraction Techniques

Conventional extraction techniques are the ones which are in operation for a long period of time and are usually dependent on the solvent, heat employed or a combination of both. Some of the commonly employed techniques are Soxhlet extraction, hydro-distillation and maceration.

6.3.1.1 Solvent Extraction Method

The solvent extraction method involves the use of various polar (ethanol, methanol, water, etc.) and non-polar solvents (hexane, acetone, etc.), which behave as transporters for the desirable compound amidst distinct phases. The disparity in the extent of solubility of different compounds in various solvents can be utilized as a way for separating the compounds of interest. Polyphenolic compounds solubilize promptly in polar solvents, whilst lipids have the ability to dissolve in non-polar solvents. Comprehensively, ethanol is the most favoured solvent in view of its low price and "GRAS" (generally recognized as safe) status (Galanakis 2013).

The extraction of target compounds using solvent can be accomplished in different ways: Soxhlet method or reflux extraction method. Soxhlet method is the oldest method which was initially devised for the extraction of lipids from a mixture. This method requires the repeated reflux of solvent through the bed of sample until complete extraction takes place. The process performance is dependent on operational parameters, for instance, chemical structure of the sample, composition of the solvent and temperature employed (Lafka et al. 2011). Reflux extraction method involves mixing the sample with a compatible solvent in an agitated vessel, pursued by centrifugation and filtration process. Process efficiency is governed by numerous factors such as the solvent-to-sample ratio, extraction time and pH.

Koubala et al. (2008) successfully extracted phenolic antioxidants from winery wastes using this technique. However, Chen et al. (2001) reported certain modifications in the process for the extraction of pectin and hemicelluloses where ethanol-induced precipitated compounds were further treated with an alkali or acid.

Advantages: Low processing cost and ease of operation of the solvent extraction technique make it beneficial over other techniques.

Limitations: This technique requires prolonged periods of processing which subject heat-labile bioactive compounds to the action of harsh solvents and heat, causing their thermal degradation; thereby reducing the quality and the quantity of the target products. To increase the yield, large volumes of solvent are required, which upscales the economy of process and poses a threat to the environment with regard to their disposal (Sagar et al. 2018; Singh et al. 2017).

6.3.1.2 Hydro-Distillation Technique

Unlike the solvent extraction method, which uses organic solvents for the extraction of bioactive compounds, hydro-distillation is a technique that employs water or steam to extract a wide variety of flavonoids and other potential bioactive compounds. The process exposes the sample to hot water/steam which frees the essential oils located in the oil glands of the plant tissue. Being highly volatile in nature, these essential oils get vaporized during the distillation process, and later condensed on cooling, resulting in an immiscible mixture of an oil and aqueous phase. The product obtained (a mixture of mainly odoriferous, coloured and other phytochemicals) is moved to a separator where the element of interest and fat get separated from water. The physicochemical processes involved are hydro-diffusion, hydrolysis and thermal disintegration.

Advantages: This process is quite easy to operate.

Limitations: The process is suitable for extracting heat-stable compounds, as heat-labile compounds may undergo degradation at high temperatures used in the extraction process. Furthermore, those compounds that exert an insignificant vapour pressure at 100 °C may co-distil with the water and lead to significant losses of target compounds. Overall, the process is highly energy- and time-driven (Vankar 2004).

6.3.1.3 Maceration

The beginning of the process marks with the grinding of the sample containing the product of interest into tiny particles in order to expand its surface area. Subsequently, menstruum (appropriate quantity of the solvent) is poured onto the sample with continuous agitation so as to accelerate the diffusion process and remove the concentrated solution from the surface. Large volumes of prepared solution are obtained after pressing the solid residue followed by the filtration process to remove impurities from the extract.

Advantages: The technique is of low cost.

Limitations: The technique is mostly suitable for carrying out low extractions at small-scale level only (Sagar et al. 2018).

6.3.2 Novel Extraction Techniques

With the upgradation in mechanization, novel techniques have been witnessed to overcome the limitations of conventional extraction techniques. The use of green technologies has brought about an upsurge in the overall yield, quality and purity of the product of interest, along with reduced process time and waste volumes. These major novel techniques are described below:

6.3.2.1 Supercritical Fluid Extraction (SFE)

SFE exposes the analyte between different phases (separation and stationary phase); and the extraction is governed by the fundamental thermodynamic properties of solvents at their supercritical point (Giannuzzo et al. 2003). This point is termed as "the specific temperature (Tc) or pressure (Pc), above which gas and liquid behaves as one phase", whereby the solvent exhibits the characteristics of liquids (density and salvation power) and gas (viscosity, diffusion and surface tension) simultaneously. This behaviour expedites greater extraction of bioactive compounds within short interval of time (Ameer et al. 2017). The selection of supercritical solvent is critical for efficacious working of this process. In comparison to ethane, butane, water and pentane, carbon dioxide is the preferred solvent as it is safe and the desirable conditions (30.9 °C and 73.8 bars) can easily be met, yet its low polarity limits the use as an individual solvent. However, this problem is possibly corrected by employing polar solvents as modifying agents, which certainly, by fixing the solvating capacity of carbon dioxide, amplify its extraction performance. These modifying agents can be methanol, ethanol, dichloromethane, acetone, etc. (Sihvonen et al. 1999). Supercritical carbon dioxide (SC-CO_2) when used in association with modifiers significantly enhances the product yield, as exemplified in the case of naringenin, a type of flavonoid from citrus waste, which was extracted in higher amounts at 9.5 MPa and 58.6 °C in the presence of ethanol than pure SC-CO_2, as reported by Giannuzzo et al. (2003). Similarly, procyanidins and polyphenols were extracted from seeds and peel of grapes by employing the methanol-modified CO_2 (Ashraf-Khorassani and Taylor 2004). Furthermore, this technique is commercially exploited for the recovery of hydroxytyrosol from olive mill waste (Lafka et al. 2011) and extraction of antioxidants from Brazilian cherry seeds (Santos et al. 2011).

Advantages: Carbon dioxide, by virtue of its non-explosive and non-toxic nature, is considered as an inexpensive alternate to organic solvents (Wang and Weller 2006).

Limitations: The scalability of the SFE technique is of major concern due to limited diffusivity of the solvent within the matrix, prolonged extraction period, immense-pressure specifications, intricacy amongst operational parameters, expensive infrastructure and divergence in the product characteristics (such as consistency). Moreover, separation of the solvent from the target product by the end of the SFE process is required that is achieved by several downstream processing steps. This difficulty is surmounted by reconciliating the SFE process with pre-processing steps involving fractionation and chemical/enzymatic conversion of wastes for adequate extraction and purification of bioactive compounds (Ameer et al. 2017).

6.3.2.2 Microwave-Assisted Extraction (MAE)

The extraction process is accomplished by exposing the sample to the electromagnetic field of microwaves ranging between 300 MHz and 300 GHz, although the widely employed frequency is 2450 MHz. The underlying principle of the technique is that as the microwaves pass through the solvent carrying the sample, energy is absorbed and this energy is later converted to thermal energy by the reason of dielectric properties of the solvent, effectuating the disruption of the hydrogen bonds. This action generates dipole moment amongst the molecules leading to the transfer of ions which diffuses solvent into the sample matrix, provoking the dissolution of the target components in the solvent (Datta et al. 2005; Zhang et al. 2011). The proficiency of the process is affected by many factors like the composition of solvent, microwave range, temperature during extraction, extraction time and sample matrix. The choice of solvent is dependent on its dielectric properties (dielectric constant and dielectric loss), and how it interacts with the sample. Dielectric constant relates with the capacity of the solvent to absorb microwave energy and dielectric loss refers to its ability to convert this absorbed energy into heat (Chen et al. 2001).

Inoue et al. (2010) has used the skin of *Citrus unshiu* fruit to extract significant amounts of hesperidin by using the microwaves. Likewise, Chandrasekar et al. (2015) extracted phenolic compounds from apple pomace and described the role of dissipation factor, dielectric constant, solubility and type of the solvent employed on the turnout of these compounds.

Advantages: Higher extraction in much shorter time, diminished solvent demand and low-priced, this technique is superior over conventional methods of extraction (Delazar et al. 2012). This makes the technique most suitable for extracting thermolabile bioactive constituents by adopting a composite solvent that possesses a lower dielectric loss factor (Koubala et al. 2008).

Limitations: Presently, this process is not exploited to a great extent in the food industry, certainly, due to rigorous food quality and safety regulations. The solvent used during extraction is compelled to be removed which involves additional purification steps that hike up the process economy (Singh et al. 2017).

6.3.2.3 Ultrasound-Assisted Extraction (UAE)

This technique is based upon the exposure of fruits and vegetables waste to sound waves (frequency range 20–2000 kHz). As the sound waves travel through the sample matrix, expansion and compression cycles are induced which tear the molecules apart and unite them, respectively, creating bubbles that grow and collapse gradually. This cavitation process is known to disrupt the cell walls and boost the transfer of target compounds from cellular matrix into the extracting solvents. Such a technique is applied for processing liquid–liquid or liquid–solid samples and the competency of the process is influenced by operational parameters like pressure, temperature, frequency and sonication time (Kentish and Feng 2014). Shen et al. (2017) concluded frequency as the critical factor that influences the yield and the properties of the compound.

Anthocyanins and phenolic compounds from grape peel (Ghafoor et al. 2011) and other valuable elements from winter melon seeds (Bimakr et al. 2013) were successfully extracted by this technique.

Advantages: UAE is considered as an elementary and effective technique in comparison to traditional methods for the extraction of bioactive compounds from fruits and vegetables waste. The technique offers low cost in terms of the structure and operation scheme when compared to other novel techniques like microwave-assisted extraction and supercritical fluid extraction. Since the process works at low temperature conditions, thermal degradation of phytonutrients is prevented and extraction time is greatly reduced (Virot et al. 2010).

Limitations: The use of this technique is limited by its reduced capacity and lower yield compared to other methods.

6.3.2.4 Enzyme-Assisted Extraction (EAE)

The phytonutrients present in fruits and vegetables are majorly located in the cytoplasm of the cell where cell walls composed of polysaccharides (pectins, hemicellulose and cellulose) hinder the release of these targeted intracellular compounds. The treatment of these cells with enzymes (xylanase, β-glucosidase, cellulase, pectinase and β-gluconase) under the influence of mild conditions and aqueous solutions degrades the cell wall structures and aids in the release of target compounds (Gardossi et al. 2010; Moore et al. 2006). The performance of this technique is a function of enzyme concentration, sample composition, water/solid ratio, molecular size of target compounds and time required for hydrolysis.

EAE is quite useful for the separation of numerous compounds like carotenoids from pumpkin (Ghosh and Biswas 2015), anthocyanins from *Crocus sativus* (Lotfi et al. 2015) and grape skin (Muñoz et al. 2004), and lycopene from tomato peel (Zuorro et al. 2011).

Advantages: This technique uses water as an alternative to organic solvent, which distinguishes it from other techniques and referred to it as an environment-friendly technology for the separation of bioactive elements from the waste material.

Limitations: The use of this technique is restrained by the cost of the enzyme which poses difficulty in scaling up the process. However, this limitation is overcome by using an immobilization approach for enzymes which promotes enzyme reuse without compromising its specificity and activity (Puri et al. 2012).

6.3.2.5 Pulsed Electric Field (PEF)

It is a non-thermal processing technique that employs direct current to the sample rather than giving thermal treatment. When high-voltage current is allowed to pass through the sample matrix for fraction of seconds (usually in the range of microseconds to milliseconds), the molecules of cell membranes align themselves according to their respective charges. Over a short span of time, the critical value of transmembrane potential reaches 1 V, thereby increasing the repulsion amongst the charged molecules and widening the pores in the membrane resulting in increase in its permeability (Bryant and Wolfe 1987). The process is operational in either batch or continuous method and the product yield is a function of strength of the field applied, specific energy input, pulse frequency, material characteristics and treatment temperature (Heinz et al. 2003). An electric field ranging between 500 and 1000 V/cm impedes undue rise in temperature, thereby minimizing the degradation of heat-sensitive compounds (Ade-Omowaye et al. 2001).

The PEF technique is found to be most suitable for the extraction of anthocyanin monoglucosides from grape by-products (Corrales et al. 2008), anthocyanins and polyphenols from "Merlot" grapeskin (Delsart et al. 2012), phenolic and flavonoid compounds from orange peel (Luengo et al. 2013).

Advantages: The technique is eco-friendly and can be utilized for the extraction of high-valued bioactive compounds (anthocyanins, betanines, carotenoids, etc.) in substantial amounts within a short span of time. Moreover, as the process is non-thermal in nature, the quality of the final product is not compromised (Liu et al. 2018).

6.4 Utilization of Bioactive Compounds in Food

Non-edible portions of the fruits and vegetables lie between 25 and 30%; however in case of exotic fruits, this proportion further increases resulting in the generation of higher masses of by-products and waste when compared to the corresponding valuable edible portions, thereby altering the economics of the industry. This obstacle can be rectified to some extent by transforming the waste to a valued product that possesses reasonable monetary worth (Sun-Waterhouse et al. 2009).

Keeping this in consideration, Gowe (2015) concluded that fruits and vegetables waste can be presented as an innovative, natural and monetary source of nutraceutical compounds (viz protein, dietary fibre, etc.) and food additives (flavouring agents, colouring compound, antimicrobial compounds, etc.).

6.4.1 Nutraceutical and Functional Compounds

Nutraceutical and functional foods are emerging trends in the food industry due to the ever-increasing demand of consumers for "healthy" food. Such compounds besides providing nutrition play determinant task in boosting health and immunity and latterly halting and conjointly treating specific diseases. Fruits and vegetables are rich and unexploited sources of these functional ingredients. Mango peel constitutes dietary fibre, phenolic compounds, vitamin C, carotenoids, which are well identified for their effects in jeopardizing the cancer, cataract, Parkinson's and Alzheimer's disease (Ayala-Zavala et al. 2010). Núñez Selles et al. (2016) proclaimed that mangiferin (1,3,6,7-tetrahydroxyxanthone-C2-β-D-glucoside) which is a native bioactive xanthonoid of the mango tree *(Mangifera indica)*, either singly or in combination, is associated with positive effects in treating leukaemia and cervix, brain, breast, lung and prostate cancers. Grape seed oil is reported to be a satisfactory source of unsaturated fatty acids, specifically oleic and linoleic acids (8–15% w/w), which corresponds to over and above 89% of the aggregate oil composition (Davidov-Pardo and McClements 2015). Ismail et al. (2015) enlisted the role of grape seed oil as neuroprotective, hepatoprotective and effective in reducing cholesterol levels in liver. In consideration of this, grape seed oil is used in the meat industry as a functional ingredient in order to modify and formulate healthier food products (Choi et al. 2010). Papaya seeds accounting for 22% of the waste from papaya puree plants are known to cure sickle cell diseases and poisoning-related renal disorder (Imaga et al. 2009). Non-digestible oligosaccharides are another group of functional components, which are present in peels of many fruits and vegetables. These compounds are generally considered as prebiotics as they reach the colon undigested, where they are fermented by good microflora such as *Bifidobacteria* and *Lactic acid bacteria*, thus producing a positive effect on health (Kadirvelu et al. 2001). Dietary fibres (soluble and insoluble) are the major components of fruits and vegetables by-products and are known to produce health benefits in humans. Soluble dietary fibre is associated with blood cholesterol and restricts its intestinal absorption (Palafox-Carlos et al. 2011), whilst insoluble dietary fibre is associated with water absorption and intestinal regulation. Mango peel contains a high level of insoluble dietary fibres (45–78%) (Ajila et al. 2010). The peel of yellow passion fruit (*Passiflora edulis*) contains dietary fibre with high activity to protect individuals from diverticular diseases (Yapo and Koffi 2008).

6.4.2 Food Additives

Utilization of fruits and vegetables waste as a budding source of natural food additives has emerged out as an adequate substitute for combating environmental hazards. Besides enhancing the nutritional profile and serving potential health benefits, these compounds provide better acceptability, longevity, stability and safety to the product (Abuajah et al. 2015). Some of the commonly derived food additives are discussed below in detail.

6.4.3 Flavouring Agents

Flavour, being a key attribute of the food, is conferred by an amalgam of volatile compounds present in the matrix. These compounds are predominantly esters, aldehydes, alcohols, terpenes or their derivatives. The typical flavour of food is either due to a single compound called "impact compound" or it is the cumulative compound wherein several compounds interplay with the receptors from the nasal mucosa, thereby producing signals that are interpreted by the brain to conceive a sensory impression (Bicas et al. 2011). The waste parts of fruits and vegetables serve as wellspring of flavour and aroma compounds that meet consumer's expectations for natural, safe and healthy products. Vanilla, which is the prominent and commonly used flavour in food products, is composed of vanillin (4-hydroxy-3-methoxybenzaldehyde) and can be naturally derived from fermented pods of vanilla orchids. Nevertheless, vanillin can also be obtained from pineapple peel that contains the precursor for vanillic acid that is, ferulic acid. Use of the microbial biotransformation technique aids in the conversion of ferulic acid to vanillic acid, which can further be converted to vanillin (Priefert et al. 2001). Likewise, "furaneol" (2,5-dimethyl-4-hydroxy-3(2H)-furanone) responsible for the strawberry flavour can be derived from rhamnose which is obtained through chemical hydrolysis of citrus fruit peel (Haleva-Toledo et al. 1999). Lanza et al. (1976) manifested the use of *Ceratocystis* species to produce pineapple flavour component "ethyl butyrate" from apple pomace and coconut flavour component "δ-decalactone" from olive press cake. Oil extracted from lemon peel is commercially utilized as flavour enhancer for soft and alcoholic beverages (Lota et al. 2002).

6.4.4 Food Colorants

Colouring agents bestow colour to food products, making their physiognomy visually appealing/or assist in restoring colour losses on exposure to natural elements such as light, air, temperature, etc. or as a result of processing, storage, packaging and distribution. As majority of the fruits and vegetables are brightly coloured, their by-products turned out to be an excellent source of naturally occurring pigments such as chlorophylls, carotenoids, anthocyanins and betanins that can be produced at a relatively cheap rate and provide high stability and purity. Anthocyanins are responsible for a range of colours such as red, blue, violet, purple and magenta which can be obtained from the extracts of grape pomace, peels of red cabbage, radishes, purple sweet potatoes, red potatoes, black carrots, coffee husks, etc. (Rodriguez-Amaya 2017). Banana peels and bracts, rich in carotenoids (xanthophylls, α- and β-carotenoid) and anthocyanins (cyanidin and delphinidin) when incorporated in biscuits, culminated into a product that offers high dietary fibre content and less calories beyond affecting the colour, aroma and taste of biscuits. In this way, banana peels could be used as an effective colouring agent in combination with potent antioxidant and antimicrobial activities (Joshi 2007). Likewise, mango seed kernel and peel residue contain the carotenoids in abundance (Kodagoda and Marapana 2017). Kaur et al. (2011) utilized lycopene from tomato peels in dairy products, imparting colour to butter and ice cream. The European Union approved and regulated the commercial use of some of the colorants extracted from crude sources such as curcumin (E100), chlorophyll (E140), chlorophyllin (E141), carotenoids (β-carotene- E160a and lycopene- E160d), lutein (E161b), canthaxanthin (E161g), betanin (E162) and anthocyanins (E163) (Commission 2011).

6.4.5 Texture Modifiers

"Texture modifiers" is an umbrella term that includes all those types of agents that are involved in modifying the texture and mouthfeel of food products. Such agents encompass stabilizers, bulking agents, thickeners and emulsifiers (Saha and Bhattacharya 2010). Citrus fruits' by-products (seed powder and peel) are abundant source of pectin and dietary fibre (Sundar Raj et al. 2012), on such account these products are exclusively utilized as thickening, texturizing, gelling and stabilizing agents (M'hiri et al. 2018). Conjointly, plenty of dietary fibres in these peels fabricate them as carbohydrate-based fat replacers (Radi et al. 2009). Crizel et al. (2013) manifested the production of low-fat yogurts by incorporating fibre exclusively from orange by-products into yogurts. In a similar manner, tomato peels and seeds were incorporated into tomato sauce to improve its texture (Ortega et al. 2017). The husk of cocoa (*Theobroma cacao*) pod is another promising alternative to get an attractive supply of dietary fibre and pectin, which can undergo drying and grinding process before using them as texturizing agents. Supplementary, these pods can be used to extract juice that can be used in the preparation of hydrocolloids (Campos-Vega et al. 2018). These fibres are also extensively used in dairy products especially in ice creams, where they improve the texture and handling properties, administering smooth body and resistance to melting particularly by hindering crystal growth (Elleuch et al. 2011).

6.4.6 Antioxidants

Oxidation of food is one of the detrimental reactions that are capable of altering the flavour, colour, nutritional value and texture of food products. Besides this, the reaction may lead to the production of toxic compounds in the food which are fatal to human health. Subsequently, the need of antioxidant compounds arises, which prevents the occurrence of oxidatively induced degradation of foods and extends their shelf-life. Fruits and vegetables by-products are an abundant source of antioxidant compounds; however, their activity may vary particularly in terms of their behaviour as reducing and/or chelating agents, acidulants and enzyme inhibitors. Chemically, these compounds belong to two major groups: phenolic acid and flavonoids (Palafox-Carlos et al. 2011). Phenolic compounds being peroxide decomposers, free radical inhibitors, oxygen scavengers and metal chelating agents have shown abundant antioxidant properties. Apart from this, such compounds hold strong antitumoural, antibacterial, antiviral, anticancer, cardioprotective and antimutagenic activities (Joshi et al. 2012). Onion peels and stems (Roldán et al. 2008), mango peel and kernel (Ajila et al. 2007) have been studied extensively as hidden sources of antioxidant and antibrowning agents. Citrus fruits' peel and seeds are splendid on account of rare flavanones and many polymethoxylated flavones. Grape skin and pomace is enriched with catechin, epicatechin, epicatechin gallate and epigallocatechin, whilst grape seed extract containing flavonoids acts as a metal chelating agent, reducing agent for hydroperoxide, free radical scavengers such as superoxide, hydroxyl and 1,1-diphenyl2-picrylhydrazyl (Jacob et al. 2008). Grape pomace produced a new class of phenolic compounds with strong antioxidant properties, namely aminoethylthio-flavan-3-ol conjugates, by thiolysis of polymeric proanthocyanidins. Larrosa et al. (2002) reported on the addition of artichoke by-product extract to tomato juice and how it brings about longer shelf-life of the product, assuming high antioxidant activity of the former. Interestingly, eggplant peels rich in anthocyanins are a source of effective antioxidants (Sadilova et al. 2006). Numerous scientists practiced incorporation of these naturally derived antioxidants in a wide variety of products viz. meat, dairy and bakery products that confer additional functionality to the food products (Caleja et al. 2017; Gassara et al. 2016). Smith and Hong-Shum (2011) concluded that antioxidants, namely ascorbic acid (E300), tocopherol (E306), and β-carotene (E160a) derived from fruits and vegetables waste using adequate solvents, have been assigned GRAS (generally recognized as safe) status. Conclusively, the consumption of food with naturally occurring antioxidants, as well as antioxidant-enriched foods helps in the prevention of diseases caused by oxidative stress and such usefulness encourages the likelihood of their commercialization in favour of enhanced shelf-life of food (Pastrana-Bonilla et al. 2003).

6.4.7 Antimicrobial Compounds

Food products are highly susceptible to attack by a wide range of microorganisms and lead to spoilage, for this reason, foods are generally loaded with preservatives rendering the food safe for consumption purpose. An array of antimicrobial compounds (fungicides, salts, enzymes, essential oils and bacteriocins) can be effectively used as preservatives. Some of these compounds are obtained in significant amounts in fruits and vegetables waste such as leaves, roots, bark, pods, stalks, stems, hull, fruits, flowers, seeds, latex and rinds.

Olive leaves containing phenolic compounds exhibit some antimicrobial activity against *Bacillus cereus*, *Escherichia coli*, *Staphylococcus aureus*, *Candida albicans* and *Cryptococcus neoformans* (Talhaoui et al. 2015). Peel extracts of pomegranate (Al-Zoreky 2009) and avocado (Calderón-Oliver et al. 2016) show their activity against foodborne pathogens such as *E. coli*, *Listeria monocytogenes* and *Yersinia enterocolytica*. Papaya extract also shows good antimicrobial activity by virtue of sulphydroxyl protease that inhibits viral or microbial infection (Rajashekhara et al. 1990). Spices, being a source of phenolic compounds particularly capsaicin, gingerone and zingerone, are capable of restricting the growth and multiplication of bacterial spores (Burt 2004). The polyphenols present in green tea (*Camellia sinensis*) fight against different microorganisms such as *Shigella*, *Vibrio cholerae* and *Streptococcus mutans* (Si et al. 2006). The functionality of bioactive compounds as an antimicrobial preservative in foods is gaining interest amongst food processors in order to replace chemical preservatives, make the food nutritious and safe and supports reducing environmental impact. However, the major hitch in its vast utilization in food industry is limited due to lack of their approval for edible purposes.

6.5 Bioactive Compounds for Human Health

Bioactive compounds are food components primarily that influence physiological, metabolic or cellular activities of the humans or animals. Flavonoids, anthocyanins, betalains, tannins, carotenoids, plant sterols and glucosinolates are primary bioactive components. They possess antioxidant, anti-inflammatory and anticarcinogenic properties and can work as protective shield against numerous diseases and metabolic disorders. Bioactive compounds mainly find origin in fruits and vegetables. Such compounds have peculiar effects on various chronic diseases like cancer, cardiovascular disease, certain neurological conditions, diabetes mellitus, etc. A brief account of bioactive compounds, including their chemistry, sources and health benefits, is given in Table 6.2. Pivotal physiological and cellular activities of such bioactive compounds in the prevention of diseases are deliberated here in particular.

6.5.1 Effects of Bioactive Compounds on Chronic Diseases

Cancer is one of the dominant causes of death worldwide. The global cancer patients have multiplied to 18.1 million as new cases and 9.6 million cancer deaths took place in 2018, approximately (World Health Organization 2018). In addition, the increment in deaths because of cancer cases has predicted, which will continue over the next decade too. For a fact, the consumption of enough fruits and vegetables containing superb biological activity is one of the easiest courses to prevent and curb the risk of cancer. A number of investigations have demonstrated the positive

Table 6.2 Health benefits of various bioactive compounds in fruits and vegetables (Walia et al. 2019)

S. no. 4	Bioactive compounds	Chemistry	Waste sources	Health benefits
1.	Flavonoids	Two benzene rings linked to a three-carbon chain, which forms a closed pyran ring	Apple, berries, carrots, cabbage, leeks, onion, ginger, broccoli, grapefruit, kale, tomato, parsley, lemon	• Act as influential antioxidants • Neutralize free radicals and restrict damage to cells and other body tissues • Exert anti-inflammatory and anti-ageing characteristics • Studies depicted relationship amidst certain polyphenols and preventive effects on diseases as cancers, cardiovascular disease and neurodegenerative diseases • Potential to improvise the quality of blood vessel walls • Supportive effect on the nervous system • Help in regulating brain blood flow, result in better cognitive function
2.	Anthocyanins	A phenolic molecule containing 15 carbon atoms and perceived as two benzene rings joined by a chain with three carbons. Accumulation of flavylium nucleus is responsible for its hyperreactivity	Acai, blueberry, blackcurrant, bilberry, cherry, red grape and purple corn	• Conclusive effects on the cardiovascular state of health, anticancer and anti-inflammatory activities
3.	Tannins	Complex mixtures of polymeric polyphenols with gallic acid in terms of a base unit	Pomegranates, persimmons, berries such as cranberries, strawberries, blueberries, grapes, red wine, and spices such as cinnamon, vanilla, cloves, thyme	• Contain antioxidant properties that prevent the tissues from the free radicals by virtue of cellular ageing and other physiological processes • Bring about good effects on health by accelerating blood clotting, reducing blood pressure, decreasing serum lipid levels and immune response modulation • The quantity and quality of tannins are critical to these effects

(continued)

Table 6.2 (continued)

S. no. 4	Bioactive compounds	Chemistry	Waste sources	Health benefits
4.	Betalains	These are indole-derived pigments that are divided into the red-violet betacyanins and the yellow betaxanthins. These are water-soluble pigments	Red and yellow beetroot, leafy or green amaranth, coloured swiss chard, red pitahaya, prickly pear	• Progressive health effects by virtue of antioxidant, anticancer, antimicrobial and antilipidaemic activities • Potential functional foods to reinforce therapies in diseases related to inflammation, oxidative stress and dyslipidaemia like arterial stenosis, atherosclerosis, hypertension and cancer
5.	Carotenoids	Consist of eight isoprenoid units linked in an order that the placement of isoprene units is turned reverse in the molecule centre Cause the elements to be deeply coloured yellow, orange or red	Carrots, plums, mangoes, apricots, cantaloupes, sweet potatoes, kale, coriander, spinach, collard greens, turnip greens, fresh thyme and winter squash	• Exert protective effects for various types of cancers like lung cancer, breast cancer, prostate cancer, and head and neck cancers • Benefit vision and skin. • Being a precursor of vitamin, the carotenoids improve immune system, skin and mucous membranes, and eye health • As indicated by studies, amongst the risk-related biological conditions, the pro-oxidant influences of β-carotene are suspected in the onset of lung cancer • Carotenoid-rich food has been demonstrated to decline the signs of illness related to eye strain (dry eye, headaches and blurred vision) and boost night vision • Commercial supplements of β-carotene are considered like oral sunscreens due to their antioxidant action, exerting protective influence on skin from the sunlight and noxious ultraviolet (UV) radiation

6.	Glucosinolates	Contain a central carbon atom, bounded via a sulphur and a nitrogen atom to the thioglucose group and to a sulphate group, respectively, to form a sulphated aldoxime. Also, the central carbon is obligated to a specifically distinct side group. Glucosinolates with different side groups are responsible for the varied biological activities of these plant compounds	Cruciferous vegetables, such as wasabi, cabbage, broccoli, kale, watercress and garden cress	• Glucosinolates and their biologically active metabolites, specifically as isothiocyanates, work as protective agents against cancer and dementia • These peculiar biochemical substances, which are rarely found in other vegetables, have been designated as efficient in the destruction of various cancer cells without harming healthy cells • Risk of dementia is lowered and the cognitive decline rate slowed down in the elderly

relationship of carotenoid-rich fruits and vegetables consumption with decreased risk of cancer, specifically lung cancer, prostate cancer, breast cancer and head and neck cancers (Leoncini et al. 2015). In the background of lung cancer, several studies reported a decline in morbidity by β-carotene supplementation in non-smoking adults as subjects (Vieira et al. 2016). Further, the recent studies on the diet of non-smoker lung cancer patients revealed an inverse trend between the carotene-rich diet including α-carotene, β-carotene, lutein, lycopene and β-cryptoxanthin, and lung cancer risk (Albanes et al. 1996). Beta-carotene and retinol efficacy trial indicated a diverse tendency between the men and women who were at the stage of high-risk lung cancer development (smokers and asbestos workers), and highly alcoholic subjects (Goodman et al. 2004). All the while, a recent detailed analysis turned out the unforeseen "cancerogenic" (pro-oxidant) effects of supplementation of carotene in individuals with unhealthy lifestyle. Many epidemiological studies support the concept of bolstering in minimizing the risk of prostate cancer by several carotenes, and also their rich sources (Soares Nda et al. 2015). Amongst various carotenoids, the investigations came up with various manners of lycopene action with respect to enrichment of the oxidation stress defence system. Evidently, as per the recent meta-analysis of the observational studies related to the role-play of tomato-based products and lycopene, the roles played by them to inhibit prostate cancer were apparent. Recent human intervention and clinical trials supported the basis of this research (Stahl and Sies 2005). Several researches have shown the decisive role of β-carotene in preventing head, breast, mouth, pharynx and larynx cancers (Leoncini et al. 2015). Such studies further suggested the reduction in the risk of head and neck cancers nearly by 50% by consuming diet with high composition of fruits and vegetables. Some other research-based facts have also exhibited the correlations between the fruits and vegetables consumption and certainty of prevention from oesophageal, colon and other gut cancers (Stahl and Sies 2005). Previous experimental studies have presented increasing evidence for the health benefits of flavonoids on multiple biological pathways related to cancer including carcinogen bioactivation, cell signalling, cell cycle regulation, angiogenesis, oxidative stress and inflammation. Whereas the epidemiologic data of cancer in relation to flavonoids are still scantier and contradictory, a few protective correlations have been implied to flavonoid-rich foods such as soy-based products and pre-menopausal breast cancer; green tea extracts and stomach cancer; onion-based products and extracts and lung cancer (Le Marchand 2002). Lechner and Stoner (2019) has also demonstrated the positive effect of betanin pigments of red beetroot as an effective cancer chemopreventor in an animal study and suggested the requirement of a detailed human study in this regard.

6.5.2 Effects of Bioactive Compounds on Diabetes Mellitus

Bioactive compounds of fruits and vegetables are capable of evolving a potential defence system to counter several diseases and metabolic disorders due to their antioxidant, anti-inflammatory and immunoprotective effects. Such properties designate them as potential protective and preventive means for Type 1 and Type 2 diabetes mellitus also (Oh and Jun 2014). Flavonoids and isoflavonoids are common polyphenolic compounds of fruits and vegetables. Being efficient antioxidants with anti-inflammatory and immunoprotective properties, they can aid in the fight against certain metabolic diseases. Numerous collaborated investigations and randomized trials considered the flavonoids as a risk-lowing factor for type-2 diabetes and cardiovascular disease. Moreover, randomized trials under meta-analyses produce the evidences for beneficial role of flavonoids in curtailing LDL-cholesterol, insulin sensitivity and endothelial function (Grassi et al. 2015; Vandenberghe et al. 2000). Genistein is one of the supreme isoflavones with regard to diabetes, which is abundantly found in plant sources including fava beans, lupine, soybeans and their products. The promising demeanour of genistein for complementary approach for preventing or treating diabetes based on different cell-culture and animal-based investigations has established its productive influences on β-cell function. A human clinical trial on post-menopausal women after giving a dose of genistein (54 mg/day) illustrated the effect of reducing fasting glucose and enhancing the glucose tolerance and the insulin sensitivity (Gilbert and Liu 2013). Lycopene, being one of the strongest antioxidant amongst carotenoids, is acclaimed in promoting health by preventing chronic diseases as cancer and cardiovascular diseases. An animal study, covering exogenous administration of particular bit-by-bit doses of lycopene to hyperglycaemic rats, brought about a drop in glucose level that was dose-dependent, subsequent rise in the concentration of insulin and improvisation in serum lipid profile. In addition, total antioxidant status was multiplied with improved antioxidant enzyme activities. This investigation culminated in the fact that the antidiabetic activity of lycopene proceeds mainly by lowering the free radical activity (Ali and Agha 2009). Various fruits, vegetables and flowers in human diet gain their characteristic colour extensively via anthocyanins and anthocyanidins. Several in vitro studies have revealed the act of anthocyanins and anthocyanidins in stimulating insulin secretion and subsequent protective effects on β-cells of pancreas (Sun et al. 2012). A mass analysis of a total of 3,645,585 women and men was conducted by Wedick et al. (2012), who were not having diseases like diabetes, cardiovascular disease and cancer during outset of the study. In subsequent pursuit of the study, in 12,611 cases out of the masses type-2 diabetes was noted. An anthocyanin-based diet in this study, particularly containing blueberries, apples and pears, was found to be associated with a lower risk of type-2 diabetes in respective masses. The other investigation claimed that the consumption of pomegranate juice (384 mg/dL anthocyanins) by diabetic patients showed antioxidative effects accounting for a considerable decline in serum lipid peroxides (56%) and the oxidative state of their monocytes/macrophages (28%) (Rosenblat et al. 2006).

6.5.3 Effects of Bioactive Compounds on Cardiovascular Diseases

Oxidative stress and inflammation are the basic causes behind the prevalence of atherosclerosis and cardiovascular diseases. The protective roles of bioactive compounds of fruits and vegetables waste were proposed to be related to inhibit oxidative, inflammatory and metabolic stress. Whole berries are rich in components such as polyphenols, particularly anthocyanins, micronutrients and fibre. Several studies claimed the association of berries in promoting heart health. A few investigations using chokeberries, blueberries, cranberries and strawberries in various forms such as fresh form, juice, freeze-dried extracts or powders and purified anthocyanin extracts were carried out. Resulted berries-based products exhibited noticeable improvements in LDL (low-density lipoproteins) oxidation, lipid peroxidation, dyslipidaemia, glucose metabolism and total plasma antioxidant capacity. Whereas, these data depict the partial support in the recommendation of berries being an essential fruit group in relation to a healthy-heart diet (Basu et al. 2010). Studies in many disciplines and randomized trials have implied the part of flavonoids in minimizing the risk of cardiovascular disease, specifically by exerting their healthful influence on LDL-cholesterol, endothelial function and insulin sensitivity (van Dam et al. 2013). A methodical review concentrating on the meta-analyses of several prospectives has also suggested a significant decrease in the risk of cardiovascular disease by intake of six varied classes of flavonoids, viz. anthocyanidins, proanthocyanidins, flavonols, flavones, flavanones and flavan-3-ols (Wang et al. 2014).

6.6 Conclusions and Future Prospects

The multi-dimensional investigations concerning bioactive compounds derived from specific food residues as of fruits and vegetables and the accessibility of highly responsive measurement tools pave the way for great opportunities for appraising respective metabolites in varied food wastes. Diverse bioactive compounds have been evaluated and construed for their vigilant human health effects. They have peculiar antioxidant, anti-inflammatory and anticarcinogenic properties, besides linked with physiological and cellular effects that are involved in preventing varied chronic diseases and metabolic disorders likewise diabetes, cardiovascular disease, cancer, etc. Being the vital components of fruits and vegetables waste and their consumption as whole fruit and vegetable with opportune health effects compositely make them favourable for developing novel potential functional food. However, further intricate research is required to discern the explicit mechanisms of bioactive compounds' biological actions. At the same time, previous investigations deliberate great variation in realistic effects, as heterogeneity occurs in the randomized controlled trials undertaken beneath varied conditions. This postulates the scope of larger, longitudinal research further in order to ascertain rational health benefits and literal mechanism of bioactive compounds to improve human health.

Any food waste or its by-products can be utilized after extraction based on the feasibility of the process and raw material by incorporating any of the approaches aforementioned. Evidently, the supercritical fluid extraction technique was reported to be the most appropriate. Though, the feasibility of the extraction method profoundly has relied on the type of food waste and the outcome of optimization process. The utilization of bioactive compounds of fruits and vegetables waste by incorporating modern and adept bioprocessing techniques will be augmented in the value of food waste and ensued as cost reduction in formulated products. As consumers' demand for new, healthy, natural, innovative products is increasing day by day, such products can be utilized as colouring agents, flavouring agents, health-promoting supplements, nutraceuticals or as preservatives by replacing synthetic chemicals in foods. With the increasing production of fruits and vegetables, post-harvest losses and the industries based on them are also multiplying, which is generating colossal waste. This aforesaid waste turning into a raw material for producing bioactive compounds will be proved as an asset by generating revenue to the country, farmers and lucid utilization of natural resources. Fruits and vegetables waste usage will reduce the hardship in waste management of food-processing industries, since hazardous organic waste generation leads to crippling the environment. Extraction and utilization of bioactive compounds should be commercialized after conceptualizing the economic and technical background of it.

References

Abuajah CI, Ogbonna AC, Osuji CM (2015) Functional components and medicinal properties of food: a review. J Food Sci Technol 52(5):2522–2529. https://doi.org/10.1007/s13197-014-1396-5

Ade-Omowaye BIO, Angersbach A, Taiwo KA, Knorr D (2001) Use of pulsed electric field pre-treatment to improve dehydration characteristics of plant based foods. Trends Food Sci Technol 12:285–295

Agarwal M, Kumar A, Gupta R, Upadhyaya S (2012) Extraction of polyphenol, flavonoid from Emblica officinalis, Citrus limon, Cucumis sativus and evaluation of their antioxidant activity. Orient J Chem 28(2):993

Ajila CM, Naidu KA, Bhat SG, Rao UJSP (2007) Bioactive compounds and antioxidant potential of mango peel extract. Food Chem 105(3):982–988. https://doi.org/10.1016/j.foodchem.2007.04.052

Ajila C, Aalami M, Krishnarau L, Prasada Rao U (2010) Mango peel powder: a potential source of antioxidant and dietary fiber in macaroni preparations. Innov Food Sci Emerg Technol 11:219–224. https://doi.org/10.1016/j.ifset.2009.10.004

Albanes D, Heinonen OP, Taylor PR, Virtamo J, Edwards BK, Rautalahti M, Hartman AM, Palmgren J, Freedman LS, Haapakoski J, Barrett MJ, Pietinen P, Malila N, Tala E, Liippo K, Salomaa ER, Tangrea JA, Teppo L, Askin FB, Taskinen E, Erozan Y, Greenwald P, Huttunen JK (1996) Alpha-tocopherol and beta-carotene supplements and lung cancer incidence in the alpha-tocopherol, beta-carotene cancer prevention study: effects of base-line characteristics and study compliance. J Natl Cancer Inst 88(21):1560–1570. https://doi.org/10.1093/jnci/88.21.1560

Alexandra Pazmiño-Durán E, Giusti MM, Wrolstad RE, Glória MBA (2001) Anthocyanins from banana bracts (Musa X paradisiaca) as potential food colorants. Food Chem 73(3):327–332. https://doi.org/10.1016/S0308-8146(00)00305-8

Al-Farsi MA, Lee CY (2008) Optimization of phenolics and dietary fibre extraction from date seeds. Food Chem 108:977–985

Ali MM, Agha FG (2009) Amelioration of streptozotocin-induced diabetes mellitus, oxidative stress and dyslipidemia in rats by tomato extract lycopene. Scand J Clin Lab Invest 69(3):371–379. https://doi.org/10.1080/00365510802658473

Al-Zoreky NS (2009) Antimicrobial activity of pomegranate *(*Punica granatum *L.)* fruit peels. Int J Food Microbiol 134(3):244–248. https://doi.org/10.1016/j.ijfoodmicro.2009.07.002

Ameer K, Shahbaz HM, Kwon J-H (2017) Green extraction methods for polyphenols from plant matrices and their byproducts: a review. Comp Rev Food Sci Food Safety 16(2):295–315. https://doi.org/10.1111/1541-4337.12253

Ashraf-Khorassani M, Taylor LT (2004) Sequential fractionation of grape seeds into oils, polyphenols, and procyanidins via a single system employing CO_2-based fluids. J Agric Food Chem 52(9):2440–2444. https://doi.org/10.1021/jf030510n

Ayala-Zavala JF, Rosas-Domínguez C, Vega-Vega V, González-Aguilar GA (2010) Antioxidant enrichment and antimicrobial protection of fresh-cut fruits using their own byproducts: looking for integral exploitation. J Food Sci 75(8):R175–R181. https://doi.org/10.1111/j.1750-3841.2010.01792.x

Balasundram N, Sundram K, Samman S (2006) Phenolic compounds in plants and agri-industrial by-products: antioxidant activity, occurrence, and potential uses. Food Chem 99:191–203

Basu A, Rhone M, Lyons TJ (2010) Berries: emerging impact on cardiovascular health. Nutr Rev 68(3):168–177. https://doi.org/10.1111/j.1753-4887.2010.00273.x

Ben-Othman S, Jõudu I, Bhat R (2020) Bioactives from agri-food wastes: present insights and future challenges. Molecules (Basel, Switzerland) 25(3):510. https://doi.org/10.3390/molecules25030510

Besbes S, Blecker C, Deroanne C, Lognay G, Drira NE, Attia H (2005) Heating effects on some quality characteristics of date seed oil. Food Chem 91:469–476

Bicas JL, Molina G, Dionísio AP, Barros FFC, Wagner R, Maróstica MR, Pastore GM (2011) Volatile constituents of exotic fruits from Brazil. Food Res Int 44(7):1843–1855

Bimakr M, Rahman RA, Taip F, Adzahan NM, Sarker ZI, Ganjloo A (2013) Ultrasound-assisted extraction of valuable compounds from winter melon (*Benincasa hispida*) seeds. Int Food Res J 20:331–338

Bryant G, Wolfe J (1987) Electromechanical stresses produced in the plasma membranes of suspended cells by applied electric fields. J Membr Biol 96:129–139

Burt S (2004) Essential oils: their antibacterial properties and potential applications in foods—a review. Food Microbiol 94:223–254

Calderón-Oliver M, Escalona-Buendía HB, Medina-Campos ON, Pedraza-Chaverri J, Pedroza-Islas R, Ponce-Alquicira E (2016) Optimization of the antioxidant and antimicrobial response of the combined effect of nisin and avocado byproducts. LWT—Food Sci Technol 65:46–52. https://doi.org/10.1016/j.lwt.2015.07.048

Caleja C, Barros L, Antonio AL, Oliveira MBPP, Ferreira ICFR (2017) A comparative study between natural and synthetic antioxidants: evaluation of their performance after incorporation into biscuits. Food Chem 216:342–346. https://doi.org/10.1016/j.foodchem.2016.08.075

Campos-Vega R, Nieto-Figueroa KH, Oomah BD (2018) Cocoa *(*Theobroma cacao *L.)* pod husk: renewable source of bioactive compounds. Trends Food Sci Technol 81:172–184. https://doi.org/10.1016/j.tifs.2018.09.022

Chandrasekar V, Martín-González MFS, Hirst P, Ballard TS (2015) Optimizing microwave-assisted extraction of phenolic antioxidants from red delicious and Jonathan apple pomace. J Food Process Eng 38(6):571–582. https://doi.org/10.1111/jfpe.12187

Chang S, Tan C, Franke EN, Barrett DM (2000) Low-density lipoprotein antioxidant activity of phenolic compounds and polyphenol oxidase activity in selected clingstone peach cultivar. J Agric Food Chem 48:47–51

Chen T, Xuegang S, Xiao W, Liu X, Zhang W, Ma K, Zhu Y (2001) Optimization of microwave-assisted extraction of solanesol from potato leaves and stems. Med Chem Res 19:732–742. https://doi.org/10.1007/s00044-009-9226-4

Choi YS, Choi JH, Han DJ, Kim HY, Lee MA, Jeong JY, Chung HJ, Kim CJ (2010) Effects of replacing pork back fat with vegetable oils and rice bran fiber on the quality of reduced-fat frankfurters. Meat Sci 84(3):557–563. https://doi.org/10.1016/j.meatsci.2009.10.012

Choi S-H, Kozukue N, Kim H, Friedman M (2016) Analysis of protein amino acids, non-protein amino acids and metabolites, dietary protein, glucose, fructose, sucrose, phenolic, and flavonoid content and antioxidative properties of potato tubers, peels, and cortexes (pulps). J Food Comp Anal 50:77–87

Coll MD, Coll L, Laencina J, Tomás-Barberán FA (1998) Recovery of flavanones from wastes of industrially processed lemons. Zeitschrift für Lebensmitteluntersuchung und -Forschung A 206(6):404–407. https://doi.org/10.1007/s002170050282

Commission E (2011) Commission Regulation (EU) No 1129/2011 of 11 November 2011 amending Annex II to Regulation (EC) No 1333/2008 of the European Parliament and of the Council by Establishing a Union List of Food Additives Text with EEA Relevance. European Commission, Brussels, Belgium

Corrales M, Toepfl S, Butz P, Knorr D, Tauscher B (2008) Extraction of anthocyanins from grape by-product assisted by ultrasonics, high hydrostatic pressure or pulsed electric fields: a comparison. Innov Food Sci Emerg Technol 9:85–91. https://doi.org/10.1016/j.ifset.2007.06.002

Crizel TM, Jablonski A, Rios AO, Rech R, Flôres SH (2013) Dietary fiber from orange byproducts as a potential fat replacer. LWT—Food Sci Technol 53(1):9–14. https://doi.org/10.1016/j.lwt.2013.02.002

Czech A, Zarycka E, Yanovych D, Zasadna Z, Grzegorczyk I, Kłys S (2020) Mineral content of the pulp and peel of various citrus fruit cultivars. Biol Trace Elem Res 193(2):555–563. https://doi.org/10.1007/s12011-019-01727-1

Datta AK, Sumnu G, Raghavan GSV (2005) Dielectric properties of foods. In: Rao MA, Rizvi SSH, Datta AK (eds) Engineering properties of foods, 3rd edn. Taylor & Francis, Boca Raton

Davidov-Pardo G, McClements DJ (2015) Nutraceutical delivery systems: resveratrol encapsulation in grape seed oil nanoemulsions formed by spontaneous emulsification. Food Chem 167: 205–212. https://doi.org/10.1016/j.foodchem.2014.06.082

Del Valle M, Camara M, Torija ME (2006) Chemical characterization of tomato pomace. J Sci Food Agric 86:1232–1236

Delazar A, Nahar L, Hamedeyazdan S, Sarker SD (2012) Microwave-assisted extraction in natural products isolation. Methods Mol Biol 864:89–115. https://doi.org/10.1007/978-1-61779-624-1_5

Delsart C, Ghidossi R, Poupot C, Cholet C, Grimi N, Vorobiev E, Milisic V, Peuchot MM (2012) Enhanced extraction of valuable compounds from merlot grapes by pulsed electric field. Am J Enol Viticul 63:205–211

Dewanto V, Wu X, Liu RH (2002) Processed sweet corn has higher antioxidant activity. J Agric Food Chem 50(17):4959–4964. https://doi.org/10.1021/jf0255937

Dhillon GS, Brar SK, Verma M, Tyagi RD (2011) Enhanced solid-state citric acid bio-production using apple pomace waste through surface response methodology. J Appl Microbiol 110:1045–1055

Elleuch M, Bedigian D, Roiseux O, Besbes S, Blecker C, Attia H (2011) Dietary fibre and fibre-rich by-products of food processing: characterisation, technological functionality and commercial applications: a review. Food Chem 124(2):411–421

Friedman M (1997) Chemistry, biochemistry, and dietary role of potato polyphenols: a review. J Agric Food Chem 45:1523–1540

Galanakis CM (2013) Emerging technologies for the production of nutraceuticals from agricultural by-products: a viewpoint of opportunities and challenges. Food Bioprod Process 91(4):575–579

Gardossi L, Poulsen PB, Ballesteros A, Hult K, Svedas VK, Vasić-Racki D, Carrea G, Magnusson A, Schmid A, Wohlgemuth R, Halling PJ (2010) Guidelines for reporting of biocatalytic reactions. Trends Biotechnol 28(4):171–180. https://doi.org/10.1016/j.tibtech.2010.01.001

Gassara F, Kouassi AP, Brar SK, Belkacemi K (2016) Green alternatives to nitrates and nitrites in meat-based products—a review. Crit Rev Food Sci Nutr 56(13):2133–2148. https://doi.org/10.1080/10408398.2013.812610

Ghafoor K, Hui T, Choi YH (2011) Optimization of ultrasonic-assisted extraction of total anthocyanins from grape peel using response surface methodology. J Food Biochem 35(3):735–746. https://doi.org/10.1111/j.1745-4514.2010.00413.x

Ghosh D, Biswas PK (2015) Enzyme-aided extraction of carotenoids from pumpkin tissues. Indian Chem Eng 58:1–11

Giannuzzo AN, Boggetti HJ, Nazareno MA, Mishima HT (2003) Supercritical fluid extraction of naringin from the peel of Citrus paradisi. Phytochem Anal 14(4):221–223. https://doi.org/10.1002/pca.706

Gilbert ER, Liu D (2013) Anti-diabetic functions of soy isoflavone genistein: mechanisms underlying its effects on pancreatic β-cell function. Food Funct 4(2):200–212. https://doi.org/10.1039/c2fo30199g

Gonzalez-Centeno MR, Rossell C, Simal S, Garau MC, Lopez F, Femenia A (2010) Physico-chemical properties of cell wall materials obtained from ten grape varieties and their byproducts: grape pomaces and stems. LWT-Food Sci Technol 43:1580–1586

Goodman GE, Thornquist MD, Balmes J, Cullen MR, Meyskens FL Jr, Omenn GS, Valanis B, Williams JH Jr (2004) The beta-carotene and retinol efficacy trial: incidence of lung cancer and cardiovascular disease mortality during 6-year follow-up after stopping beta-carotene and retinol supplements. J Natl Cancer Inst 96(23):1743–1750. https://doi.org/10.1093/jnci/djh320

Gorinstein S, Martín-Belloso O, Park YS, Haruenkit R, Lojek A, Cız M, Caspi A, Libman I, Trakhtenberg S (2001) Comparison of some biochemical characteristics of different citrus fruits. Food Chem 74:309–315

Gowe C (2015) Review on potential use of fruit and vegetables by-products as a valuable source of natural food additives. Food Sci Qual Manage 45:47–61

Grassi D, Desideri G, Mai F, Martella L, De Feo M, Soddu D, Fellini E, Veneri M, Stamerra CA, Ferri C (2015) Cocoa, glucose tolerance, and insulin signaling: cardiometabolic Protection. J Agric Food Chem 63(45):9919–9926. https://doi.org/10.1021/acs.jafc.5b00913

Haleva-Toledo E, Naim M, Zehavi U, Rouseff RL (1999) Effects of L-cysteine and N-acetyl-L-cysteine on 4-hydroxy-2, 5-dimethyl-3 (2H)-furanone (furaneol), 5-(hydroxymethyl) furfural, and 5-methylfurfural formation and browning in buffer solutions containing either rhamnose or glucose and arginine. J Agric Food Chem 47:4140–4145

Heinz V, Toepfl S, Knorr D (2003) Impact of temperature on lethality and energy efficiency of apple juice pasteurization by pulsed electric fields treatment. Innov Food Sci Emerg Technol 4:167–175. https://doi.org/10.1016/S1466-8564(03)00017-1

Hollman PCH, Arts ICW (2000) Flavonols, flavones and flavanols—nature, occurrence and dietary burden. J Sci Food Agric 80(7):1081–1093. https://doi.org/10.1002/(sici)1097-0010(20000515)80:7<1081::aid-jsfa566>3.0.co;2-g

Ignat I, Volf I, Popa VI (2011) A critical review of methods for characterisation of polyphenolic compounds in fruits and vegetables. Food Chem 126:1821–1835

Imaga N, Gbenle G, Okochi V, Akanbi S, Edeoghon S, Oigbochie V, Kehinde M, Bamiro S (2009) Antisickling property of Carica papaya leaf extract. Afr J Biochem Res 3:102–106

Imandi SB, Bandaru VVR, Somalanka SR, Bandaru SR, Garapati HR (2008) Application of statistical experimental designs for the optimization of medium constituents for the production of citric acid from pineapple waste. Bioresour Technol 99:4445–4450

Inoue T, Tsubaki S, Ogawa K, Onishi K, Azuma J (2010) Isolation of hesperidin from peels of thinned Citrus unshiu fruits by microwave-assisted extraction. Food Chem 123:542–547

Ismail AF, Moawed FS, Mohamed MA (2015) Protective mechanism of grape seed oil on carbon tetrachloride-induced brain damage in γ-irradiated rats. J Photochem Photobiol B Biol 153:317–323. https://doi.org/10.1016/j.jphotobiol.2015.10.005

Jacob JK, Hakimuddin F, Paliyath G, Fisher H (2008) Antioxidant and antiproliferative activity of polyphenols in novel high polyphenol grape lines. Food Res Int 41(4):419

John RP, Nampoothiri KM, Pandey A (2006) Solid-state fermentation for L-lactic acid production from agro wastes using *Lactobacillus delbrueckii*. Process Biochem 41:759–763

Joshi RVJ (2007) Low calorie biscuits from banana peel pulp. Solid Waste Technol Manage 33: 142–147

Joshi V, Kumar A, Kumar V (2012) Antimicrobial, antioxidant and phyto-chemicals from fruit and vegetable wastes: a review. Int J Food Ferment Technol 2:123–136

Kadirvelu K, Thamaraiselvi K, Namasivayam C (2001) Removal of heavy metals from industrial wastewaters by adsorption onto activated carbon prepared from an agricultural solid waste. Bioresour Technol 76(1):63–65. https://doi.org/10.1016/s0960-8524(00)00072-9

Kallel F, Driss D, Chaari F, Belghith L, Bouaziz F, Ghorbel R, Chaabouni SE (2014) Garlic (*Allium sativum* L.) husk waste as a potential source of phenolic compounds: influence of extracting solvents on its antimicrobial and antioxidant properties. Ind Crop Prod 62:34–41. https://doi.org/10.1016/j.indcrop.2014.07.047

Kaur D, Wani AA, Singh DP, Sogi DS (2011) Shelf life enhancement of butter, ice-cream, and mayonnaise by addition of lycopene. Int J Food Properties 14(6):1217–1231. https://doi.org/10.1080/10942911003637335

Kentish S, Feng H (2014) Applications of power ultrasound in food processing. Annu Rev Food Sci Technol 5:263–284

Kodagoda G, Marapana U (2017) Utilization of fruit processing by-products for industrial applications: a review. Int J Food Sci Nutr 24:2455–4898

Koubala BB, Mbome LI, Kansci G, Tchouanguep Mbiapo F, Crepeau MJ, Thibault JF, Ralet MC (2008) Physicochemical properties of pectins from ambarella peels (*Spondias cytherea*) obtained using different extraction conditions. Food Chem 106(3):1202–1207. https://doi.org/10.1016/j.foodchem.2007.07.065

Kujala T, Loponen J, Pihlaja K (2001) Betalains and phenolics in red beetroot (Beta vulgaris) peel extracts: extraction and characterisation. Zeitschrift für Naturforschung C 56(5–6):343. https://doi.org/10.1515/znc-2001-5-604

Kummu M, de Moel H, Porkka M, Siebert S, Varis O, Ward PJ (2012) Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Sci Total Environ 438:477–489

Lafka TL, Lazou AE, Sinanoglou VJ, Lazos ES (2011) Phenolic and antioxidant potential of olive oil mill wastes. Food Chem 125(1):92–98. https://doi.org/10.1016/j.foodchem.2010.08.041

Lanza E, Ko KH, Palmer JK (1976) Aroma production by cultures of *Ceratocystis moniliformis*. J Agric Food Chem 24:1247–1250

Larrosa M, Llorach R, Espín JC, Tomás-Barberán FA (2002) Increase of antioxidant activity of tomato juice upon functionalisation with vegetable by-product extracts. LWT—Food Sci Technol 35(6):532–542. https://doi.org/10.1006/fstl.2002.0907

Le Marchand L (2002) Cancer preventive effects of flavonoids-a review. Biomed Pharmacother 56(6):296–301. https://doi.org/10.1016/s0753-3322(02)00186-5

Lechner JF, Stoner GD (2019) Red beetroot and betalains as cancer chemopreventative agents. Molecules (Basel, Switzerland) 24(8):1602. https://doi.org/10.3390/molecules24081602

Leoncini E, Nedovic D, Panic N, Pastorino R, Edefonti V, Boccia S (2015) Carotenoid intake from natural sources and head and neck cancer: a systematic review and meta-analysis of epidemiological studies. Cancer Epidemiol Biomark Prev 24(7):1003. https://doi.org/10.1158/1055-9965.EPI-15-0053

Liu RH (2004) Potential synergy of phytochemicals in cancer prevention: mechanism of action. J Nutr 134(12 Suppl):3479S–3485S. https://doi.org/10.1093/jn/134.12.3479S

Liu RH (2013) Dietary bioactive compounds and their health implications. J Food Sci 78(1):18–25. https://doi.org/10.1111/1750-3841.12101

Liu Z-W, Zeng X-A, Ngadi M (2018) Enhanced extraction of phenolic compounds from onion by pulsed electric field (PEF). J Food Process Preserv 42(9):e13755. https://doi.org/10.1111/jfpp.13755

Lota M-L, de Rocca SD, Tomi F, Jacquemond C, Casanova J (2002) Volatile components of peel and leaf oils of lemon and lime species. J Agric Food Chem 50(4):796–805. https://doi.org/10.1021/jf010924l

Lotfi L, Kalbasi-Ashtari A, Hamedi M, Ghorbani F (2015) Effects of enzymatic extraction on anthocyanins yield of saffron tepals (*Crocos sativus*) along with its color properties and structural stability. J Food Drug Anal 23(2):210–218. https://doi.org/10.1016/j.jfda.2014.10.011

Luengo E, Álvarez I, Raso J (2013) Improving the pressing extraction of polyphenols of orange peel by pulsed electric fields. Innov Food Sci Emerg Technol 17:79–84. https://doi.org/10.1016/j.ifset.2012.10.005

M'hiri N, Ghali R, Ben Nasr I, Boudhrioua N (2018) Effect of different drying processes on functional properties of industrial lemon byproduct. Process Safety Environ Protect 116:450–460. https://doi.org/10.1016/j.psep.2018.03.004

Moo-Huchin VM, Moo-Huchin MI, Estrada-León RJ, Cuevas-Glory L, Estrada-Mota IA, Ortiz-Vázquez E, Betancur-Ancona D, Sauri-Duch E (2015) Antioxidant compounds, antioxidant activity and phenolic content in peel from three tropical fruits from Yucatan, Mexico. Food Chem 166:17–22. https://doi.org/10.1016/j.foodchem.2014.05.127

Moore J, Cheng Z, Su L, Yu LL (2006) Effects of solid-state enzymatic treatments on the antioxidant properties of wheat bran. J Agric Food Chem 54(24):9032–9045. https://doi.org/10.1021/jf0616715

Muñoz O, Sepúlveda M, Schwartz M (2004) Effects of enzymatic treatment on anthocyanic pigments from grapes skin from Chilean wine. Food Chem 87:487–490. https://doi.org/10.1016/j.foodchem.2003.12.024

Núñez Selles AJ, Daglia M, Rastrelli L (2016) The potential role of mangiferin in cancer treatment through its immunomodulatory, anti-angiogenic, apoptopic, and gene regulatory effects. Biofactors 42(5):475–491. https://doi.org/10.1002/biof.1299

Oh YS, Jun HS (2014) Role of bioactive food components in diabetes prevention: effects on Beta-cell function and preservation. Nutr Metab Insights 7:51–59. https://doi.org/10.4137/nmi.s13589

Ortega MGG, Ruiz-Roso MR, Bermejo AC. (2017). Obtaining enriched fried tomato sauce using tomato byproducts. In: Paper presented at the Proceedings of the XIV International Symposium on Processing Tomato, Leuven, Belgium

Palafox-Carlos H, Ayala-Zavala JF, González-Aguilar GA (2011) The role of dietary fiber in the bioaccessibility and bioavailability of fruit and vegetable antioxidants. J Food Sci 76(1):R6–R15. https://doi.org/10.1111/j.1750-3841.2010.01957.x

Panda SK, Mishra SS, Kayitesi E, Ray RC (2016) Microbial-processing of fruit and vegetable wastes for production of vital enzymes and organic acids: biotechnology and scopes. Environ Res 146:161–172

Parker TL, Wang XH, Pazmiño J, Engeseth NJ (2007) Antioxidant capacity and phenolic content of grapes, sun-dried raisins, and golden raisins and their effect on ex vivo serum antioxidant capacity. J Agric Food Chem 55(21):8472–8477. https://doi.org/10.1021/jf071468p

Pastrana-Bonilla E, Akoh CC, Sellappan S, Krewer G (2003) Phenolic content and antioxidant capacity of muscadine grapes. J Agric Food Chem 51:4497–4503

Prabha MS, Rangaiah GS (2014) Citric acid production using Ananas comosusn and its waste with the effect of alcohols. Int J Curr Microbiolo Appl 3:747–754

Price KR, Rhodes MJC (1997) Analysis of the major flavonol glycosides present in four varieties of onion (*Allium cepa*) and changes in composition resulting from autolysis. J Sci Food Agric 74(3):331–339. https://doi.org/10.1002/(sici)1097-0010(199707)74:3<331::aid-jsfa806>3.0.co;2-c

Priefert H, Rabenhorst J, Steinbuchel A (2001) Biotechnology production of vanillin. Appl Microbiol Biotechnol 56:296–314

Puri M, Sharma D, Barrow CJ (2012) Enzyme-assisted extraction of bioactives from plants. Trends Biotechnol 30(1):37–44. https://doi.org/10.1016/j.tibtech.2011.06.014

Radi M, Niakousari M, Amiri S (2009) Physicochemical, textural and sensory properties of low-fat yogurt produced by using modified wheat starch as a fat replacer. J Appl Sci 9:2194–2197

Rajashekhara E, Tippannavar CM, Sreenivasa MN, Sharma JS (1990) Inhibition activity of papain on facultative pathogens. Zentralblatt Fuer Microbiologie 145:455–456
Raybaudi-Massilia RM, Mosqueda-Melgar J, Soliva-Fortuny R, Martín-Belloso O (2009) Control of pathogenic and spoilage microorganisms in fresh-cut fruits and fruit juices by traditional and alternative natural antimicrobials. Comp Rev Food Sci Food Safety 8(3):157–180. https://doi.org/10.1111/j.1541-4337.2009.00076.x
Rodriguez-Amaya DB (ed) (2017) Natural food pigments and colorants. Springer International Publishing, Switzerland
Roldán E, Sánchez-Moreno C, de Ancos B, Cano MP (2008) Characterisation of onion (Allium cepa *L.*) by-products as food ingredients with antioxidant and antibrowning properties. Food Chem 108(3):907–916. https://doi.org/10.1016/j.foodchem.2007.11.058
Rosenblat M, Hayek T, Aviram M (2006) Anti-oxidative effects of pomegranate juice (PJ) consumption by diabetic patients on serum and on macrophages. Atherosclerosis 187(2):363–371. https://doi.org/10.1016/j.atherosclerosis.2005.09.006
Sadilova E, Stintzing FC, Carle R (2006) Anthocyanins, colour and antioxidant properties of eggplant *(*Solanum melongena *L.)* and violet pepper *(*Capsicum annuum *L.)* peel extracts. Zeitschrift für Naturforschung C 61:527–535
Sagar NA, Pareek S, Sharma S, Yahia EM, Lobo MG (2018) Fruit and vegetable waste: bioactive compounds, their extraction, and possible utilization. Comp Rev Food Sci Food Safety 17(3):512–531. https://doi.org/10.1111/1541-4337.12330
Saha D, Bhattacharya S (2010) Hydrocolloids as thickening and gelling agents in food: a critical review. J Food Sci Technol 47(6):587–597. https://doi.org/10.1007/s13197-010-0162-6
Saito M, Hosoyama H, Ariga T, Kataoka S, Yamaji N (1998) Antiulcer activity of grape seed extract and procyanidins. J Agric Food Chem 46(4):1460–1464. https://doi.org/10.1021/jf9709156
Santos DN, De Souza LL, Ferreira NJ, De Oliveira AL (2011) Process variables study on supercritical CO_2 extraction of Brazilian cherry seeds *(*Eugenia uniflora *L.)* rich in bioactive volatile. Food Process Eng Chang World:1669–1670
Schieber A, Ullrich W, Carle R (2000) Characterization of polyphenols in mango puree concentrate by HPLC with diode array and mass spectrometric detection. Innov Food Sci Emerg Technol 1(2):161–166. https://doi.org/10.1016/S1466-8564(00)00015-1
Schieber A, Stintzing FC, Carle R (2001) By-products of plant food processing as a source of functional compounds--recent developments. Trends Food Sci Technol 12(11):401–413. https://doi.org/10.1016/s0924-2244(02)00012-2
Sharma SK, Le Maguer M (1996) Lycopene in tomatoes and tomato pulp fractions. Italian J Food Sci 8(2):107–113
Shen X, Shao S, Guo M (2017) Ultrasound-induced changes in physical and functional properties of whey proteins. Int J Food Sci Technol 52(2):381–388. https://doi.org/10.1111/ijfs.13292
Shrikhande AJ (2000) Wine by-products with health benefits. Food Res Int 33:469–474
Si WD, Gong J, Tsao R, Kalab M, Yang R, Yin YL (2006) Bioassayguided purification and identification of antimicrobial components in Chinese green tea extract. J Chromatogr 1125: 204–210
Sihvonen M, Järvenpää E, Hietaniemi V, Huopalahti R (1999) Advances in supercritical carbon dioxide technologies. Trends Food Sci Technol 10(6):217–222
Singh A, Raghavan V, Md Salim NS (2017) Potential utilization of fruit and vegetable wastes for food through drying or extraction techniques. Novel Tech Nutr Food Sci 1:15–27. https://doi.org/10.31031/NTNF.2017.01.000506
Smith J, Hong-Shum L (2011) Food additives data book. John Wiley & Sons, New York, NY
Soares Nda C, Teodoro AJ, Lotsch PF, Granjeiro JM, Borojevic R (2015) Anticancer properties of carotenoids in prostate cancer. a review. Histol Histopathol 30(10):1143–1154. https://doi.org/10.14670/hh-11-635
Someya S, Yoshiki Y, Okubo K (2002) Antioxidant compounds from bananas (Musa cavendish). Food Chem 79:351–355

Song W, Derito CM, Liu MK, He X, Dong M, Liu RH (2010) Cellular antioxidant activity of common vegetables. J Agric Food Chem 58(11):6621–6629. https://doi.org/10.1021/jf9035832
Sonia NS, Mini C, Geethalekshmi PR (2016) Vegetable peels as natural antioxidants for processed foods: a review. Agric Rev 37:35–41
Soong YY, Barlow PJ (2004) Antioxidant activity and phenolic content of selected fruit seeds. Food Chem 88:411–417
Souquet J-M, Cheynier V, Brossaud F, Moutounet M (1996) Polymeric proanthocyanidins from grape skins. Phytochemistry 43(2):509–512. https://doi.org/10.1016/0031-9422(96)00301-9
Stahl W, Sies H (2005) Bioactivity and protective effects of natural carotenoids. Biochim Biophys Acta 1740(2):101–107. https://doi.org/10.1016/j.bbadis.2004.12.006
Subagio A, Morita N, Sawada S (1996) Carotenoids and their fatty-acid esters in banana peel. J Nutr Sci Vitaminol 42(6):553–566. https://doi.org/10.3177/jnsv.42.553
Sun C-D, Zhang B, Zhang J-K, Xu C-J, Wu Y-L, Li X, Chen K-S (2012) Cyanidin-3-glucoside-rich extract from Chinese bayberry fruit protects pancreatic β cells and ameliorates hyperglycemia in streptozotocin-induced diabetic mice. J Med Food 15(3):288–298. https://doi.org/10.1089/jmf.2011.1806
Sundar Raj A, Rubila S, Jayabalan R, Ranganathan T (2012) A review on pectin: chemistry due to general properties of pectin and its pharmaceutical uses. Sci Rep 1:550–551
Sun-Waterhouse D, Wen I, Wibisono R, Melton LD, Wadhwa S (2009) Evaluation of the extraction efficiency for polyphenol extracts from by-products of green kiwifruit juicing. Int J Food Sci Technol 44(12):2644–2652. https://doi.org/10.1111/j.1365-2621.2009.02097.x
Swain MR, Ray RC, Patra JK (2011) Citric acid: microbial production and applications in food and pharmaceutical industries. Nova Science Publishers, Hauppauge, New York
Talhaoui N, Taamalli A, Gómez-Caravaca AM, Fernández-Gutiérrez A, Segura-Carretero A (2015) Phenolic compounds in olive leaves: Analytical determination, biotic and abiotic influence, and health benefits. Food Res Int 77:92–108. https://doi.org/10.1016/j.foodres.2015.09.011
Teleszko M, Wojdyło A (2015) Comparison of phenolic compounds and antioxidant potential between selected edible fruits and their leaves. J Funct Foods 14:736–746. https://doi.org/10.1016/j.jff.2015.02.041
Thomas M, Badr A, Desjardins Y, Gosselin A, Angers P (2018) Characterization of industrial broccoli discards (Brassica oleracea var. italica) for their glucosinolate, polyphenol and flavonoid contents using UPLC MS/MS and spectrophotometric methods. Food Chem 245:1204–1211. https://doi.org/10.1016/j.foodchem.2017.11.021
Toor RK, Savage GP (2005) Antioxidant activity in different fractions of tomatoes. Food Res Int 38:487–494
Tripathi P, Dubey NK (2004) Exploitation of natural products as an alternative strategy to control postharvest fungal rotting of fruit and vegetables. Postharvest Biol Technol 32(3):235–245. https://doi.org/10.1016/j.postharvbio.2003.11.005
van Dam RM, Naidoo N, Landberg R (2013) Dietary flavonoids and the development of type 2 diabetes and cardiovascular diseases: review of recent findings. Current Opin Lipidol 24(1):25–33. https://doi.org/10.1097/mol.0b013e32835bcdff
Vandenberghe LP, Soccol CR, Pandey A, Lebeault JM (2000) Solid-state fermentation for the synthesis of citric acid by *Aspergillus niger*. Bioresour Technol 74:175–178
Vankar PS (2004) Essential oils and fragrances from natural sources. Resonance 9(4):30–41. https://doi.org/10.1007/BF02834854
Vieira AR, Abar L, Vingeliene S, Chan DS, Aune D, Navarro-Rosenblatt D, Stevens C, Greenwood D, Norat T (2016) Fruits, vegetables and lung cancer risk: a systematic review and meta-analysis. Ann Oncol 27(1):81–96. https://doi.org/10.1093/annonc/mdv381
Vilariño MV, Franco C, Quarrington C (2017) Food loss and waste reduction as an integral part of a circular economy. Front Environ Sci 5(21)
Virot M, Tomao V, Le Bourvellec C, Renard CM, Chemat F (2010) Towards the industrial production of antioxidants from food processing by-products with ultrasound-assisted extraction. Ultrason Sonochem 17(6):1066–1074

Walia A, Gupta AK, Sharma V (2019) Role of bioactive compounds in human health. Acta Scientific Med Sci 3(9)
Wang L, Weller CL (2006) Recent advances in extraction of nutraceuticals from plants. Trends Food Sci Technol 17:300–312
Wang X, Ouyang YY, Liu J, Zhao G (2014) Flavonoid intake and risk of CVD: a systematic review and meta-analysis of prospective cohort studies. Br J Nutr 111(1):1–11. https://doi.org/10.1017/s000711451300278x
Wedick NM, Pan A, Cassidy A, Rimm EB, Sampson L, Rosner B, Willett W, Hu FB, Sun Q, van Dam RM (2012) Dietary flavonoid intakes and risk of type 2 diabetes in US men and women. Am J Clin Nutr 95(4):925–933. https://doi.org/10.3945/ajcn.111.028894
Wolfe KL, Liu RH (2003) Apple peels as a value-added food ingredient. J Agric Food Chem 51: 1676–1683
World Health Organization (2018) Latest global cancer data: Cancer burden rises to 18.1 million new cases and 9.6 million cancer deaths in 2018. World Health Organization, Geneva
Yapo BM, Koffi KL (2008) Dietary fiber components in yellow passion fruit rind- a potential fiber source. J Agric and Food Chem 56(14):5880–5883. https://doi.org/10.1021/jf073247p
Zeyada NN, Zeitoum MAM, Barbary OM (2008) Utilization of some vegetables and fruit waste as natural antioxidants. Alex J Food Sci Technol 5:1–11
Zhang W, Yao Y, Sullivan N, Chen Y (2011) Modeling the primary size effects of citrate-coated silver nanoparticles on their ion release kinetics. Environ Sci Technol 45(10):4422–4428. https://doi.org/10.1021/es104205a
Zhao B, Hall CA 3rd (2008) Composition and antioxidant activity of raisin extracts obtained from various solvents. Food Chem 108(2):511–518. https://doi.org/10.1016/j.foodchem.2007.11.003
Zuorro A, Fidaleo M, Lavecchia R (2011) Enzyme-assisted extraction of lycopene from tomato processing waste. Enzyme Microbial Technol 49(6–7):567–573. https://doi.org/10.1016/j.enzmictec.2011.04.020